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PLANNING WATER RESOURCE MANAGEMENT IN PISHIN-LORA RIVER BASIN OF BALOCHISTAN USING GIS/RS TECHNIQUES

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ABSTRACT

The recent drought (1998-2004) in water deficient province of Balochistan (the largest province of Pakistan) affected the availability of seasonal rainwater and vegetation cover. Analysis of the spatial rainfall computed through spatial interpolation of point rainfall depicted a reduction of about 53–85 percent and 66–90 percent in volumes of rainwater during summer and winter seasons of the drought period, respectively. Spatio-temporal analysis of the vegetation cover carried out through land cover classification of satellite images revealed a reduction of up to 31 percent in summer season and 5–7 percent in winter season vegetation cover in Balochistan during the drought period. In addition to the direct impacts of this period of dry weather, significant increase in the number of tubewells in order to overcome the water deficiency during recent drought in the province resulted in over-abstraction of groundwater, particularly in the Pishin-Lora river basin. An average lowering of water table by 1–20 m per year in Pishin-Lora river basin triggered the process of identification of potential recharge sites in this heavily populated river basin. A methodology to delineate the potential groundwater recharge zones by means of Geographical Information Systems and Remotely Sensed datasets was devised and spatial analyses were conducted using surface slope, drainage network, lithology and settlements in Pishin-Lora river basin. The results showed that about 50 percent of the basin had medium to high potential for recharging groundwater and the potential recharge areas were identified as the active zones for implementation of artificial recharge mechanisms for enhancement of groundwater recharge.

Keywords: Balochistan, Pishin-Lora, Drought, Water, GIS, RS

1. INTRODUCTION

Water is a scarce resource in Pakistan but more specifically in the province of Balochistan [1]. Comprising an area of 347,000 km^2 (44 % of Pakistan), the province is situated towards the south-west of Pakistan and is bordered with Iran to the west, Afghanistan and Federally Administrated Tribal Areas (FATA) to the north, and the provinces of Punjab and Sindh to the east. Towards south, the province has a coastline with the Arabian Sea (Figure 1). Despite the largest province of the country, Balochistan represents only about 5 percent of the total population of Pakistan (7 million out of total 140 million according to 1998 census) [2]. The population is mainly concentrated in the provincial capital Quetta located towards north-west of the province. Population density in rest of the area is quite low due to unfriendly terrain, erratic climatic conditions and most importantly, scarcity of water resources.

Climatically, Balochistan ranges from semi-arid to hyper-arid conditions characterized by scarce and spatially scattered rainfall, and high evaporation rates [3]. Mean annual rainfall ranges from less than 50 mm in western deserts to more than 400 mm in northern highlands, whereas the annual evaporation rate exceeds 2000 mm [1]. The spatial availability of water in the province is 23 percent (556 m^3/ha/annum) of that of Pakistan (2453 m^3/ha/annum) [1]. However, most of the water runs off rapidly due to high stream gradients.

The province comprises thirteen major river basins and the flow of almost all the rivers is characterized by springs runoff and occasional flash floods. Out of total water available per annum in Balochistan (27.73 billion m^3), 96 percent is contributed by surface water and only 4 percent is contributed by groundwater [4], [5] and [6]. Two systems constitute the surface water resources in Balochistan, floodwater and the Indus Basin Irrigation System (IBIS). Floodwater is the largest source of water contributing 57 percent to the total available water. However, due to bare mountains and high variability in terrain, floodwater mostly comes in the form of flash floods and only 23 percent of this resource is utilized. The IBIS contributes 39 percent to the total available resource and is exploited by 60 percent in only 5 percent area of the province in

Kachhi Plain basin towards east of Balochistan. The rest of the province benefits largely from the groundwater due to absence of any other perennial source of water [7].

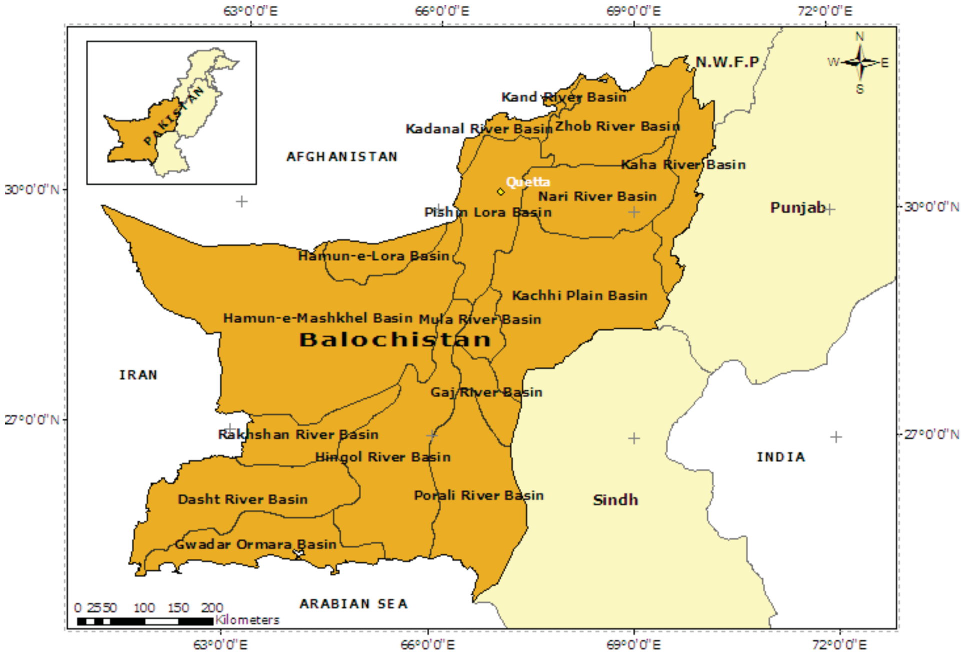

Figure 1: Geographical location of Balochistan

Groundwater is the smallest resource in terms of availability and interestingly, the largest one in terms of utilization as about 61 percent of this resource is exploited annually in Balochistan [4], [5] and [6]. Owing to the incentives offered to the farmers for installation of tubewells, the groundwater abstraction triggered primarily in 1970's [8]. In addition, the subsidized electricity tariff resulted in rapid increase in the number of tubewells, particularly in northern areas of the province where groundwater is largely utilized for fruit farming [9]. The total number of tubewells in Balochistan in 1995 were 16,294 (8,089 electric, 8,205 diesel) [8]. As the utilization of groundwater within sustainable limits was not considered, the abstraction of groundwater exceeded the amount of recharge which resulted in lowering of water table in major river basins of the province [4].

The recent drought in Balochistan, which persisted for 6 years (1998-2004), was the longest and most severe dry spell ever recorded in the history of this region [5]. Out of the total cultivated area of about 20,000 km^2 in Balochistan [8], 42 percent is under dry land agricultural production system where rainwater is the only source of irrigation. This agricultural system totally collapsed during this period [9]. However, as an attempt to sustain the agricultural yield and to meet the domestic needs of water, additional tubewells were installed to utilize the groundwater and the number of tubewells increased from 16,294 in 1995 to 27,195 in 2005 [8]. The combined impact of decrease in groundwater recharge due to reduction in rainwater and over-abstraction of groundwater during recent drought resulted in rapid depletion of groundwater in the province, particularly in the Pishin-Lora river basin [5].

Pishin-Lora river basin is assessed to be the most overdrawn river basin among other river basins of the province [10]. This heavily populated river basin is located towards north of Balochistan representing nearly 5 percent area (about 18,700 km^2) of the province. The number of tubewells in the basin in 2005 were 11,918 (10,369 electric, 1,549 diesel) constituting 44 percent of the total tubewells in Balochistan [10]. In 1991, annual groundwater depletion in the Pishin-Lora river basin was estimated to be 1.52 m/year [11]. However, due to reduction in groundwater recharge and over-abstraction of groundwater during recent drought, the depletion rate of groundwater increased and the current estimates indicate an annual decline of 1-3 m per year in the alluvial aquifer and up to 20 m annual drawdown in the hard rock aquifer in Pishin-Lora river basin [10]. Moreover, it has been estimated that the aquifer storage in the Quetta sub-basin will be exhausted in next 13 years in case if no appropriate measures are taken for conservation of groundwater in Pishin-Lora river basin [4].

The critical state of water resources in Balochistan stipulates implementation of appropriate water management strategies. Although effective resource management planning in the province faces several hurdles such as vast geographical extent, inaccessibility to many areas and high variability in terrain, the modern data acquisition and analysis techniques of Remote Sensing (RS) and Geographical Information Systems (GIS) offers the platform to handle and manipulate diverse spatial parameters. These techniques have been used effectively for planning water resource management at various spatial scales.

Several case studies addressing the droughts have concluded the effectiveness of GIS towards spatio-temporal assessment and analysis of the volumes of rainwater [12], whereas RS has been used successfully for studying vast geographical areas to analyze the temporal changes occurring in land cover [13]. Moreover, these techniques have been exploited in recent past for identification of potential recharge sites trough planned spatial analysis of the pertinent parameters [14], [15], [16] and [17]. For that reason, GIS/RS based methodologies for conservation, planning and management of water resources are widely practiced and accepted these days [18]. The present study utilizes the powerful capabilities of GIS and RS based techniques to devise a basin-scale methodology for identification of potential recharge sites in Pishin-Lora river basin. In addition, spatio-temporal analyses are also conducted at provincial-scale to get a glimpse of the impacts of recent drought in Balochistan.

2. METHODOLOGY

2.1. Impact Analysis of the Recent Drought in Balochistan

The impacts of recent drought in Balochistan were studied using two parameters, seasonal rainfall and seasonal vegetation cover. The point rainfall data was used to compute the volumes of seasonal rainwater (summer and winter seasons) and land cover satellite data was used to compute the seasonal vegetation cover (summer and winter seasons). The year of 1997 (pre-drought) was used as the base year and the period from 1998-2005 was considered as drought period. In addition, 1987 was also considered to study the situation of vegetation cover, a decade prior to the drought. The ideal months to observe the vegetation cover for summer and winter seasons are August and February, respectively. However, due to non-availability of cloud-free and error-free land cover satellite data, the month of June was selected to compute the summer season vegetation cover and December was chosen to compute the winter season vegetation cover. Likewise, in order to analyze the impacts of rainfall on vegetation cover, the rainfall data was organized for both the seasons accordingly. The summer season rainfall was calculated as total rainfall for six months prior to June and the winter season rainfall was calculated as total rainfall for six months prior to December. The volume of seasonal rainwater (summer and winter) was computed for 1987, and 1997 to 2005, whereas due to non-availability of cloud-free data for some of the years, the seasonal vegetation cover (summer and winter) was computed for 1987, 1997, 1999, 2001, 2003, 2004 and 2005.

Monthly rainfall data from 63 climatic stations in Balochistan, archived at the Bureau of Water Resources, Quetta, was used to assess and analyze the volumes of seasonal rainwater in Balochistan for the selected years. The seasonal vegetation cover for the selected years was computed and analyzed through the processed National Oceanic and Atmospheric Administration- Advanced Very High Resolution Radiometer (NOAA-AVHRR) land cover satellite data. The methodological outline followed to study the impacts of drought in Balochistan is shown in Figure 2.

The point rainfall data computed for both the seasons (summer and winter) was spatially interpolated using Inverse Distance Weighted (IDW) algorithm. The spatial interpolation algorithms work on the principle of estimating the unknown values using the known ones and IDW algorithm (out of a variety of available interpolation algorithms) is best suited for spatial interpolation in the scenario where density of known values in not as much as of the unknown ones [19], [20]. The interpolated rainfall data was then used to compute the volumes of rainwater in Balochistan through GIS based spatial analysis techniques.

The initial processing of raw NOAA-AVHRR data (geometric correction and spectral enhancement) was followed by the supervised land cover classification (based on visually interpreted spectral signatures of vegetation) of the satellite images to compute the seasonal vegetation cover in Balochistan. The classified satellite images were used to compute the geographical area of the vegetation cover in Balochistan during the selected years.

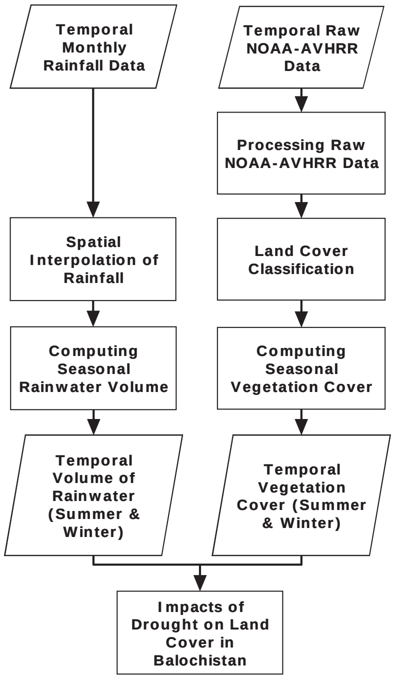

Figure 2: Methodology to observe the impacts of drought in Balochistan

2.2. Identification of Potential Sites for Recharging Groundwater in Pishin-Lora River Basin

After determining the impacts of drought on the volumes of seasonal rainwater and seasonal vegetation cover in Balochistan, a GIS/RS based methodology was devised to identify the potential recharge sites in Pishin-Lora river basin. Four parameters, surface slope, drainage network, lithology and settlements, were used to characterize the groundwater recharge potential in the basin.

The Shuttle Radar Topography Mission (SRTM) data was used to generate the Digital Elevation Model (DEM) of Pishin-Lora river basin which was further processed to obtain the surface slope and drainage network of the basin. The DEM generated drainage network was incorporated with the Digital Chart of the World (DCW) drainage network data and used in this study. The lithology of the basin was extracted through the hydrogeological maps prepared by Water and Power Development Authority (WAPDA), whereas the settlements/built-up areas were obtained through Landsat ETM+ satellite images. The methodology used for identification of potential groundwater recharge sites in Pishin-Lora river basin in shown in Figure 3.

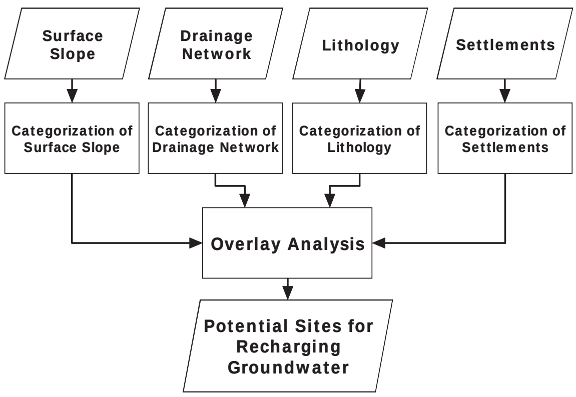

Figure 3: Methodology to identify potential sites for recharging groundwater in Pishin-Lora river basin

Since each parameter under consideration (surface slope, drainage network, lithology and settlements) has its own function towards recharging the groundwater, the parameters were categorized and ranked in accordance with their contribution and potential towards recharging groundwater. The ranks were then normalized using score range procedure to obtain equal scale values (Table 1) [21].

After re-classifying the surface slope, drainage network, lithology and settlements based on the normalized ranks of these parameters (Table 1), GIS based spatial overlay analysis was conducted in order to categorize the groundwater recharge potential in Pishin-Lora river basin.

3. RESULTS AND DISCUSSIONS

3.1. Impacts of Drought in Balochistan

The point rainfall during the recent drought in Balochistan (1998-2004) was reduced which had impacts on the volumes of seasonal rainwater (summer and winter). The volumes were computed through GIS analysis for the years of 1987 (a decade prior to drought), 1997 (pre-drought year) and with yearly interval for the duration from 1998 to 2005 (drought years) (Table 2). The variability in volumes of seasonal rainwater was analyzed using the pre-drought year of 1997, whereas 1987 was also taken as a base year to compare with the situation a decade prior to the drought.

Table 1: Ranked parameters for groundwater recharge

Parameters	Rank *	Normalized Rank *
Surface Slope		
< 5°	3	1
5° - 15°	2	0.5
< 15°	1	0
Drainage Network		
Drainage Channels with 500 m Buffer	2	1
No Drainage Channels	1	0
Lithology		
Gravel Sand	9	1
Gravel Sand, Silt and Clay	8	0.875
Sand	7	0.75
Conglomerate	6	0.625
Sandstone	5	0.5
Sand with minor Clay and Silt	4	0.375
Sandstone and Shale	3	0.25
Limestone	2	0.125
Limestone and Shale	1	0
Shale	1	0
Shale, Sandstone, Limestone, Conglomerate, and other Sedimentary Rocks	1	0
Intrusive Rocks	1	0
Settlements		
No Settlements	2	1
Settlements	1	0

** Higher values of rank and normalized rank shows higher suitability towards recharging groundwater and vice versa*

The volume of rainwater during summer season of 1987 and 1997 was nearly the same and therefore, only the year of 1997 was used to compare the volume of rainwater during the drought years. With the commencement of drought during summer of 1998, the volume of rainwater reduced by nearly 53 percent compared to summer 1997. The volume of rainwater during summers of 1999 to 2004 reduced by 53 to 85 percent from that of summer 1997. The extent of reduction in volume of rainwater during 1998-2004 depicts the severity of summer drought in Balochistan. Summer of 2002 was the worst in terms of reduction in volume of rainwater. However, wetter season of summer 2005 resulted in rise in volume of rainwater which increased by 24 percent compared to summer 1997, indicating that the summer drought was over in the province.

Table 2: Volumes of seasonal rainwater in Balochistan

Year	Volume of Seasonal Rainwater ('000' million m^3)	
	Summer	Winter
1987	25.753	7.913
1997	26.658	35.978
1998	12.066	4.402
1999	12.634	5.131
2000	4.231	4.701
2001	5.789	7.545
2002	3.93	3.447
2003	8.086	12.332
2004	5.032	4.88
2005	33.103	5.799

Since winter season of 1987 was drier and that of 1997 was exceptionally wet, therefore, the volume of rainwater during winter of 1997 varied significantly from that of 1987 (Table 2). Considering winter of 1997 as the base year, the volume of rainwater during winter of 1998 decreased by nearly 88 percent. Similar trend continued during the winters of 1999 to 2005, when the volume of rainwater reduced by 66 to 90 percent from that of winter 1997. The winter of 2002 was the worst in terms of reduction in volume of rainwater. Although the winter drought was drastic during 1998-2005, the only exception was the winter of 2003 during which, slight improvement in volume of rainwater was observed (Table 2).

The impact of recent drought on seasonal vegetation cover in Balochistan was also analyzed using the NOAA-AVHRR data for the summer and winter seasons of 1987, 1997 and for the drought years of 1999, 2001, 2003, 2004 and 2005. The drought years of 1998, 2000 and 2002 were omitted due to non-availability of cloud free satellite data for these years. The seasonal vegetation covered areas for the selected years are shown in Table 3. The variability in seasonal vegetation cover during the drought period was analyzed using the year of 1997, whereas 1987 was also taken to observe the changes in vegetation cover over the past decade.

During the period of 10 years from 1987 to 1997, the summer season vegetation cover reduced from 53,785 km^2 to 41,814 km^2, a reduction of about 22 percent (Table 3). This reduction can be attributed to the impacts of socio-economic development on degradation of rangelands and vegetation due to increased human and livestock population. However, as a consequence of nearly 53 percent decrease in volume of rainwater during summer 1999 compared to summer 1997, the vegetation cover reduced by 31 percent within 2 years. With the persistence of summer drought, the vegetation cover in summer seasons of 2001, 2003 and 2004 was reduced by about 29, 12 and 1 percent, respectively, compared to summer of 1997. Summer 1999 was the worst in terms of reduction in vegetation covered area. However, with the end of summer season drought in 2005, the seasonal vegetation cover increased by nearly 8 percent compared to summer season of 1997 indicating that impact of long drought on seasonal vegetation were almost over.

Table 3: Seasonal vegetation cover in Balochistan

Year	Summer		Winter	
	Area ('000' km^2)	%	Area ('000' km^2)	%
1987	53.785	15.50	64.784	18.67
1997	41.813	12.05	56.075	16.16
1999	29.009	8.36	51.980	14.98
2001	29.911	8.62	52.050	15.00
2003	36.643	10.56	53.125	15.31
2004	41.397	11.93	53.403	15.39
2005	44.936	12.95	56.075	16.16

Compared to winter season of 1987, the vegetation cover in winter 1997 decreased from 64,785 km^2 to 56,075 km^2, a reduction of about 13 percent during the period of 10 years (Table 3). With the commencement of drought, the vegetation cover in winter season of 1999 reduced by 7 percent compared to winter of 1997. As the winter drought continued, the vegetation cover in the winter seasons of 2001, 2003 and 2004 was reduced by about 7, 5 and 5 percent, respectively, compared to that of 1997. Winter 1999 was observed to be the worst in terms of reduction in vegetation covered area. Although winter drought persisted during 2004 and 2005, the seasonal vegetation cover improved during this period and the vegetation covered area in winter 2005 was the same as in winter 1997.

On the whole, it was evident that the recent drought (1998-2004) negatively affected the volumes of seasonal rainwater and seasonal vegetation cover in Balochistan. The impact of summer drought on vegetation cover was prominent in early drought years when reduction in vegetation cover was observed, whereas gradual improvement in vegetation was observed during summers of later drought years. This phenomenon may be linked with the reduction in livestock during 1998-2000 which resulted in decrease in grazing capacity of rangelands. The total livestock population in Balochistan according to 1996 census was about 22 million [22], however, the figures released in 2000 by the Drought Crisis Control Centre of the Government of Balochistan indicated that seven million heads of the total livestock population had been severely affected and nearly two million had perished [9].

Although the winter drought was intense in terms of reduction in volume of rainwater compared to summer drought, the vegetation cover did not varied much during winters. Reduced temperatures and evapotranspiration rates in winters may be the reason for this fact. In addition, the seasonal vegetation has noticeably reduced over the past decade which had impacts not only on the environment, but also on recharging of groundwater.

3.2. Potential Recharge Sites in Pishin-Lora River Basin

The lowering of water table and mining of groundwater in Balochistan, in general, and in Pishin-Lora basin in particular resulted in depletion of this finite resource. This problem exaggerated during recent drought because of reduction in availability of surface water and absence of appropriate recharge measures.

Four parameters namely surface slope, drainage network, lithology and settlements in Pishin-Lora river basin were analyzed using GIS techniques. It was observed that about 79 percent area of the basin had gentle to moderate slope (<15 º) and hence, suitable for the retention of surface water. About 20 percent area of the basin falling under the buffer of 500 m around the drainage channels was suitable for retaining the surface water flows, whereas about 50 percent basin area had medium to high potential for percolation of water to recharge the sub-surface aquifers (lithological formations comprising of gravel sand, gravel sand, silt and clay, sand, conglomerate, sandstone and sand with minor clay and silt). About 2 percent area of the basin having settlements was found less suitable for recharging groundwater.

Overlay analysis of the categorized surface slope, drainage network, lithology and settlements revealed the relative potential of the areas towards recharging groundwater in Pishin-Lora river basin. The recharge potential was categorized into five classes and the geographical area under each class was computed (Table 4). The spatial distribution of potential areas for recharging groundwater is shown in Figure 4.

Table 4: Groundwater recharge potential in the Pishin-Lora basin

Recharge Potential	Area (km^2)	%
Very High Potential	1321	7.1
High Potential	6079	32.5
Medium Potential	1859	9.9
Low Potential	8245	44.1
Very Low Potential	1196	6.4

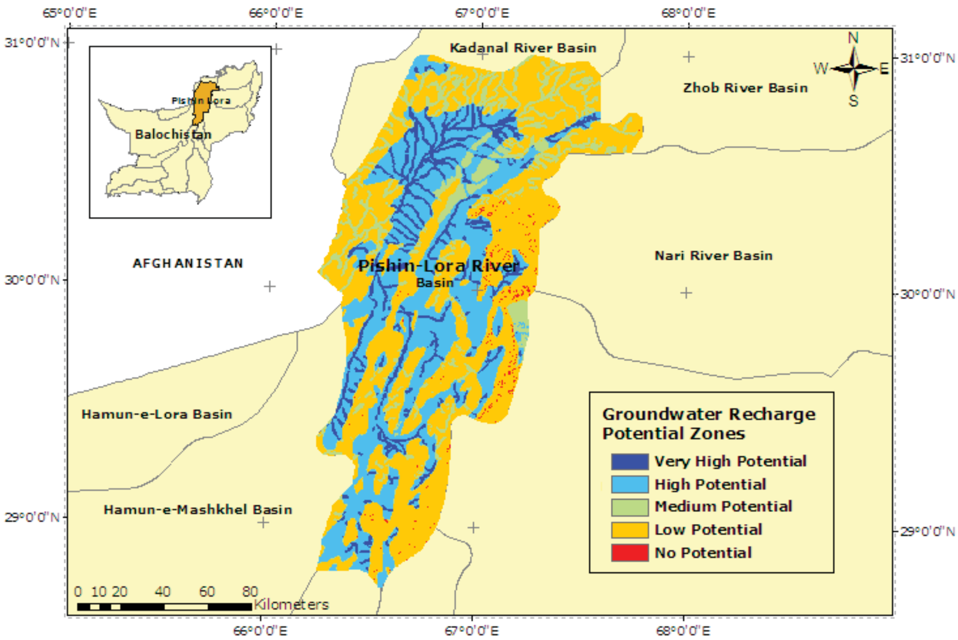

Figure 4: Groundwater recharge potential areas in the Pishin-Lora river basin

The results revealed that nearly 40 percent area of the basin had very high to high potential for groundwater recharge followed by low and very low potential area of about 50 percent and by medium potential area of about 10 percent (Table 4). Thus, almost half of the geographical area of the basin is having medium to high potential for introducing cost-effective recharge interventions such as spreading of water, storing of water in successive ponds and delay action dams.

4. CONCLUSIONS AND RECOMMENDATIONS

The decrease in rainfall during the recent drought in Balochistan (1998-2004) significantly reduced the volumes of seasonal rainwater in both the summer and winter seasons. Spatial analysis of the point rainfall depicted a reduction of about 53–85 percent and 66–90 percent in volumes of rainwater during summer and winter seasons of the drought period, respectively. Since rainwater is the most important factor affecting the vegetation, negative impacts of the drought on provincial vegetation cover were also evident. Spatio-temporal analysis of the vegetation cover, carried out through land cover classification of satellite images, revealed a reduction of up to 31 percent in summer season and 5–7 percent in winter season vegetation cover in Balochistan during the drought period. Another noticeable fact is the reduction in provincial vegetation cover over the past decade by ± 15 percent which not only affected the environment, but also resulted in decrease in interception and retention of rainwater. As a result, reduction in groundwater recharge was evident in Balochistan generally, and in Pishin-Lora river basin specifically.

In view of the fact that the lowering of water table in Pishin-Lora river basin had serious implications on the availability of domestic water supplies to the provincial capital Quetta, analyses were conducted for identification of potential recharge sites in this river basin. The spatial analysis of surface slope, drainage network, lithology and settlements revealed that about 50 percent area of Pishin-Lora river basin has medium to high potential for recharging groundwater. The potential recharge areas were identified as the active zones for watershed rehabilitation as well as for implementation of artificial recharge mechanisms for enhancement of groundwater recharge. The results of the study revealed that GIS based analytical approach provided a cost-effective option to plan for groundwater management in Pishin-Lora river basin.

Since water is a scarce resource in Balochistan, implementation of appropriate strategies for management and conservation of water is imperative in the province. In addition to efficient utilization of water by all sub-sectors of water use, conservation of groundwater is also essential to sustain the resource availability in order to meet the future requirements of water and to cope with recurring droughts. Following are some of the water-related research options that require deliberate attention:

- The GIS-based criteria for identification of potential sites for recharging groundwater can be fine-tuned through ground-validation and using high-resolution datasets. In addition, detailed hydrological parameters can be incorporated to refine the methodology. The refined GIS-based methodology could be used in other river basins as well to plan for water resource management.
- Groundwater modeling through GIS techniques can assist in resource assessment and monitoring. Moreover, analyzing the parameters affecting groundwater and simulation techniques can help in efficient and effective planning for resource management.
- Studies can be conducted to plan for effective management and efficient utilization of floodwater which is the largest water resource available in Balochistan.

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